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RESULTS OF MEASUREMENTS OF MAXIMUM LIFT AND BUFFETING INTENSITIES OBTAINED DURING FLIGHT INVESTIGATION OF THE NORTHROP X-4 RESEARCH AIRPLANE

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RESEARCH MEMORANDUM

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RESULTS OF MEASUREMENTS OF MAXIMUM LIFT AND BUFFETING INTENSITIES OBTAINED DURING FLIGHT INVESTIGATION OF THE NORTHROP X-4 RESEARCH AIRPLANE

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SUMMARY

The variation of the intensity of buffeting experienced throughout the operational region of the Northrop X-4 airplane and the values of maximum and peak normal-force coefficients in the Mach number range from about 0.40 to 0.92 have been determined. The data were obtained during turns and stalls at approximately 30,000 feet. The values of maximum lift attained by the Northrop X-4 airplane decreased from a normal-force coefficient of about 0.77 at a Mach number of 0.40 to a normal-force coefficient of 0.54 at a Mach number of 0.84. Maximum lift at Mach numbers greater than 0.84 were not attained because of insufficient longitudinal control. The low values of maximum normal-force coefficient attained by the Northrop X-4 airplane as compared with those attained by conventional (tailed) swept-wing aircraft were partially attributed to the detrimental effects of the elevons.

The buffet boundary, which separates smooth flight from buffeting flight, decreased from a normal-force coefficient of 0.515 at a Mach number of 0.425 to a constant value of 0.420 at a Mach number of 0.575. At Mach numbers greater than about 0.64, no buffet boundary could be established because of the existence of buffeting at all values of normal-force coefficient at Mach numbers greater than about 0.62. An intensity-rise boundary, above which buffet intensities increased rapidly with lift, was found to extend from a normal-force coefficient of 0.54 at a Mach number of 0.45 to a normal-force coefficient of 0.41 at a Mach number of 0.86. The maximum observed incremental fluctuations of airplane normal-force coefficient due to buffeting were of the order of $\Delta C_N = \pm 0.25$ and occurred during stalls at low Mach numbers. Buffet intensities of $\Delta C_N = \pm 0.10$ were observed during turns to maximum lift at a Mach number of approximately 0.80.

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In comparison with a conventional swept-wing airplane, the buffeting experienced by the Northrop X-4 airplane occurred at substantially lower values of normal-force coefficient but the maximum buffet intensities of the two airplanes were of the same order. When compared on an angle-of-attack basis, it was found that the intensity-rise boundaries of the two airplanes were almost coincidental.

The maneuvering range of the Northrop X-4 was found to be limited by maximum attainable lift and control ineffectiveness and was not limited by the onset of high-intensity buffeting. The magnitude of the buffeting encountered was objectionable to the pilots only at normal-force coefficients close to maximum lift. No alleviating effect, insofar as buffeting is concerned, was produced by the absence of a horizontal tail.

INTRODUCTION

The Northrop X-4 airplane was constructed as part of the joint NACA—Air Force—Navy research airplane program primarily to provide research information on stability and control characteristics at high subsonic Mach numbers. This paper presents the results of an investigation with the X-4 airplane to determine the maximum lift and buffeting characteristics of a swept-wing configuration without a horizontal tail.

Buffeting may be defined as an aerodynamically induced structural vibration of one or more components of an airplane. During previous investigations, it was found that the region in which buffeting is encountered may be defined in terms of lift coefficient (or angle of attack) and Mach number. The origin of buffeting lies in the pressure fluctuations associated with separated flow and with turbulent wakes. The structurally elastic components of the airplane (wing, stabilizers, and fuselage) generally respond to the pressure fluctuations at frequencies close to their natural structural frequencies. The vibrations of all the various components, regardless of frequency, are reflected at the airplane center of gravity as fluctuations in acceleration. The buffet data presented in this paper are the results of measurements of these acceleration fluctuations.

SYMBOLS

C_{N_A} airplane normal-force coefficient, nW/qS

$C_{N_{max}}$ maximum normal-force coefficient

h_p	pressure altitude, ft
i_w	incidence angle of wing, deg
M	Mach number
n	airplane normal load factor
p	static pressure, lb/sq ft
q	dynamic pressure, $0.7M^2P$, lb/sq ft
R	Reynolds number
S	wing area, sq ft
W	airplane weight, lb
α	airplane angle of attack, deg
α_w	angle of attack of wing, $\alpha + i_w$, deg
δ_e	elevon deflection, deg
ΔC_N	incremental fluctuation of airplane normal-force coefficient due to buffeting, $W \Delta n/qS$
Δn	incremental fluctuation of load factor due to buffeting

AIRPLANE AND INSTRUMENTATION

The Northrop X-4 airplane is a semitailless airplane having a vertical tail but no horizontal tail. Longitudinal and lateral control is achieved by elevons located on the outboard trailing edge of the wing. The elevon system is an irreversible hydraulic-powered system. No direct mechanical control of the elevons is provided for the pilot. The control stick "feel" is provided synthetically by means of springs and a force-producing bellows assembly. The airplane is powered by two Westinghouse J-30-WE-7-9 engines and is designed for flight research in the high subsonic speed range. The physical characteristics of the airplane are listed in table I. Photographs are shown in figure 1 and a three-view drawing is presented in figure 2.

Standard NACA recording instruments, synchronized by a common timer, were used to measure all quantities pertinent to this investigation.

TESTS AND PROCEDURE

The data presented were obtained during wind-up turns and accelerated stalls at approximately 30,000 feet with the airplane in the clean configuration. The Mach number range covered during maneuvering flight extended from $M \approx 0.40$ to $M \approx 0.84$. Level flight Mach numbers of the order of 0.92 were attained.

The values of maximum lift for the X-4 airplane are defined as the airplane normal-force coefficient beyond which the normal-force coefficient decreases with increase in angle of attack. The buffet intensities were determined by measuring the double amplitude of the fluctuations of the normal-acceleration trace, converting the measurements into incremental values of acceleration $\pm\Delta n$, and calculating values of incremental normal-force coefficient ΔC_N. Buffet intensities were measured only during periods of increasing normal acceleration and positive pitching velocity.

Two typical records of normal acceleration are reproduced in figure 3. The start of buffeting is indicated at time 7.7 seconds in figure 3(a). The fluctuations in normal acceleration occur predominantly at two frequencies, 11 and 30 cycles per second. Inspection of records taken during various flight conditions indicated that the most severe buffeting occurred at the lower frequency. The accelerometer used for buffet-intensity determination is an air-damped instrument having a natural frequency of 21 cycles per second. The response of this instrument varies with air density and with forcing frequency. The incremental acceleration data obtained from it have been corrected for both variants by using a forcing frequency of 11 cycles per second as the basis of frequency correction.

RESULTS AND DISCUSSION

General Flight Characteristics

The operational region of the X-4 airplane is shown in figure 4. Lines of constant normal load factor for a wing loading of 35 pounds per square foot and an altitude of 30,000 feet are shown as a matter of interest. The shaded area of figure 4 indicates the region in which buffeting is experienced. Liftwise, the airplane is limited by maximum attainable normal-force coefficients at Mach numbers below 0.84 and by longitudinal control ineffectiveness at higher Mach numbers. The maximum speed of the airplane was limited to $M \approx 0.92$ because of violent lateral and longitudinal oscillations. The longitudinal instability boundary for the airplane is shown in figure 4. Detailed presentation of the results of handling-qualities investigations with the airplane is given in reference 1.

Maximum Lift

The values of maximum lift (considered herein as synonymous with maximum normal-force coefficient) attained by the X-4 airplane (fig. 4) were considerably lower than those of conventional airplanes. Stall warning was provided by an increase in the intensity of the buffeting at normal-force coefficients about $0.1C_N$ below maximum lift. In general, the buffeting below the instability boundary is not objectional to the pilots. Detailed results of low-speed stall tests are given in references 1 to 3.

The low values of maximum normal-force coefficient attained by this airplane are the result of the use of the outboard trailing edges of the wing as lateral and longitudinal control surfaces. The considerable scatter in the values of $C_{N_{max}}$ shown in figure 4 is caused by variations in the position of the elevons. The reduction in lift caused by negative deflections of the elevons is illustrated in figure 5 where typical flight-test variation of normal-force coefficient and elevon positions with angle of attack are compared with wind-tunnel values of normal-force coefficient at various elevon positions. The wind-tunnel data through maximum lift for $\delta_e = 0^\circ$ and up to an angle of attack of 6° for deflected elevons were obtained from reference 4. At angles of attack greater than 6°, the decrement in lift due to elevon position was estimated from various published wind-tunnel data. At low values of normal-force coefficient, the flight-test data are in agreement with the wind-tunnel data but, at the stall, flight-test values of normal-force coefficient are higher than the estimated wind-tunnel values at comparative elevon positions. The differences between the data are probably due to the difference in Reynolds number but may be due to incorrect estimation of the decrement in lift caused by elevon deflection. It should be noted that, although right and left elevon positions are approximately equal in figure 5, lift can be appreciably decreased by increase in the up deflection of either elevon.

Buffeting

Buffet boundary.- The portion of the operational region of the X-4 airplane in which buffeting was experienced is presented in figure 4. As indicated in this figure, a definite line of transition between smooth flight and buffeting flight has been found to exist up to a Mach number of about 0.64. This line of transition, or buffet boundary, is defined by the Mach numbers and normal-force coefficients at which buffeting is first apparent as normal-force coefficient is increased. At Mach numbers greater than about $M = 0.62$, buffeting exists at all flight-attained values of lift coefficient, but the intensity of the buffeting is of very low intensity at normal-force coefficients less than about 0.4. At low lifts $\left(C_{N_A} \approx 0.4\right)$, the transition from smooth flight to buffeting flight occurred in the Mach number range from 0.62 to 0.64, but a definite boundary defining the exact conditions at which the transition occurred could not be determined.

Intensity of buffeting.- Typical variations of buffet intensity ΔC_N with normal-force coefficient at Mach numbers of approximately 0.61 and 0.80 are presented in figure 6. The data were obtained from the records of normal acceleration reproduced in figure 3. At the lower Mach number (fig. 6(a)) smooth flight exists until a normal-force coefficient of 0.43 is attained; whereas, in figure 6(b) $(M \approx 0.80)$, the airplane is buffeting at the start of the run $\left(C_N = 0.16\right)$. The buffeting indicated in figure 6(b) at normal-force coefficients between 0.16 and 0.43 is typical of the low-lift buffeting experienced by this airplane at Mach numbers above 0.62. At normal-force coefficients greater than 0.43 in figure 6(b), the buffet intensity increases rapidly with C_{N_A}. A similar abrupt increase in buffet intensity can be noted in figure 6(a). These abrupt increases in buffet intensity, which occur somewhat above the buffet boundary at low Mach numbers and which denote the end of low-lift buffeting at high Mach numbers, vary consistently with Mach number and normal-force coefficient and effectively establish a boundary above which buffeting can be considered induced by lift (or angle of attack). The buffet boundary and the "intensity-rise" boundary for the X-4 airplane are presented in figure 7. Although the buffet boundary separates the region of smooth flight from that in which buffeting is encountered, the intensity-rise boundary is of importance because it indicates the depth to which the buffet region can be penetrated before buffeting of increasing severity is experienced.

The variations of buffet intensity with normal-force coefficient, of which the data of figure 6 are typical, were determined for various Mach numbers throughout the speed range of the airplane. These data have been summarized in figure 8. It may be seen that a slight increase in the intensity of low-lift buffeting occurred as Mach number increased. The highest intensity of low-lift buffeting observed was on the order of $\Delta C_N = \pm 0.015$, which is considered of low intensity. The cause and nature of the low-lift buffeting which occurred at Mach numbers greater than 0.62 and normal-force coefficients below the intensity-rise are not known. The low-lift buffeting could not be felt by the pilot and had no effect on handling and maneuvering characteristics.

Inspection of the data of figure 6 shows that, at normal-force coefficients above the intensity rise, the increase in buffet intensity with lift is somewhat random. Actually, it was found that the buffet intensities experienced during several maneuvers performed under similar conditions generally fell within the envelope described by the peak values of ΔC_N during any one maneuver. The various buffet-intensity regions shown in figure 8 were determined from such envelopes. As maximum lift was approached, the increase in buffet intensity with lift was too rapid for the exact regions of constant-intensity buffeting to be shown in figure 8. The data of figure 6 are illustrative of this effect. The maximum buffet intensities observed were of the order of $\Delta C_N = \pm 0.25$ and occurred during stalls at low Mach numbers. Buffeting intensities of $\Delta C_N \approx \pm 0.10$ were experienced during turns to maximum lift at Mach numbers around 0.80. The peak value of buffet intensity that might be reached during a turn or stall to maximum lift appeared to depend on the length of time the airplane remained at maximum lift and the angle of attack attained. Control position and rate of pitch appear to have some effect on the intensity of buffeting at any given lift, but no investigations to measure these effects have been conducted.

Pilots' opinion.- Correlation of the data of figure 8 with pilots' comments indicated that buffet intensities less than about $\Delta C_N = \pm 0.02$ cannot be felt by the pilots. Buffet intensities from $\Delta C_N = \pm 0.02$ to ± 0.06 were described as "tolerable" and intensities greater than $\Delta C_N = \pm 0.06$ were termed "objectionable." It should be noted at this point that incremental accelerations rather than incremental values of normal-force coefficient form the basis for the pilots' opinion of buffeting, and, therefore, the values of ΔC_N which are determined for objectional buffeting at one altitude might not be applicable at an appreciably different altitude. Buffet frequency, wing loading, noise level, and the pilot's familiarity with buffeting flight also appear to affect what is termed tolerable or objectionable buffeting.

Buffeting frequencies.- In general, the frequencies at which an airplane buffets coincide with the natural structural frequencies of the airplane. Buffet frequencies of 11, 17, 30, and 35 cycles per second have been measured from records of normal acceleration. Higher but indeterminate frequencies were also observed. The pertinent natural structural frequencies of the airplane from reference 5 are as follows:

Mode:	Frequency, cps
First symmetrical wing bending	11.3
First unsymmetrical wing bending	15.5
First vertical fin bending	18.3
First symmetrical and unsymmetrical torsion	28.0
Second symmetrical wing bending	28.5
Second unsymmetrical wing bending	37.5

The buffet frequency most predominant in terms of amplitude and occurrence was 11.0 cycles per second, although buffeting corresponding to the torsional frequency of the wing was appreciable at high lifts and high Mach numbers. The predominant buffet frequencies of the swept-wing Douglas D-558-II airplane were similar to those of the Northrop X-4 airplane in that they corresponded to the natural structural bending and torsional frequencies of the wing.

Comparisons

The maximum lift and buffet-intensity data obtained with the X-4 airplane are compared in figure 9 with the peak normal-force coefficients and buffet intensities obtained for the D-558-II airplane. The D-558-II data are unpublished. Most of the difference between the peak airplane normal-force coefficients for the D-558-II airplane and the values of $C_{N_{max}}$ for the X-4 is attributed to a large contribution to normal force of the D-558-II fuselage at high angles of attack, but part of the difference is due to the detrimental effect on lift of the X-4 elevons. Comparison of the buffet intensities for the X-4 and D-558-II airplanes shows that the X-4 airplane buffets at substantially lower values of normal-force coefficient than does the D-558-II airplane.

The regions of high-intensity buffeting for both airplanes are indicated in figure 9 as $\Delta C_N > \pm 0.06$, but the variation of buffet intensity with normal-force coefficient for the two airplanes is not similar. The intensity of buffeting experienced by the D-558-II airplane increases more gradually with lift than does that of the X-4 airplane, and, unlike the buffeting of the X-4 airplane, the intensities measured with the D-558-II airplane appear to reach some maximum value before maximum lift is attained. The highest buffet intensities observed for the X-4 at maximum lift were of the same order as the maximum intensities encountered by the D-558-II airplane.

It is of interest to compare the intensity-rise boundaries of the two airplanes on both a normal-force coefficient and an angle-of-attack basis. These data are shown in figure 10. It is apparent that, although elevon deflection decreases the lifting effectiveness of the X-4 wing, separation and buffeting are not induced at lower angles of attack. On the other hand, the elimination of a horizontal tail on the X-4 has not alleviated the buffeting problem.

The maneuvering range of the X-4 airplane is limited by maximum lift and control ineffectiveness and is not limited by the onset of high-intensity buffeting. The maneuvering range of the more conventional D-558-II airplane is extensive at all Mach numbers but is affected by both longitudinal instability and high-intensity buffeting at normal-force coefficients substantially below the peak values shown in figure 9.

CONCLUDING REMARKS

The variation of the intensity of buffeting experienced throughout the operational region of the Northrop X-4 airplane and the values of maximum and peak normal-force coefficients in the Mach number range from about 0.40 to 0.92 have been determined. The values of maximum lift attained by the Northrop X-4 airplane decreased from a normal-force coefficient of about 0.77 at a Mach number of 0.40 to a normal-force coefficient of 0.54 at a Mach number of 0.84. Maximum lift at Mach numbers greater than 0.84 were not attained because of insufficient longitudinal control. The low values of maximum normal-force coefficient attained by the Northrop X-4 as compared to those attained by conventional (tailed) swept-wing aircraft was partially attributed to the detrimental effects of the elevons.

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In comparison with a conventional swept-wing airplane, the buffeting experienced by the Northrop X-4 airplane occurred at substantially lower values of normal-force coefficient but the maximum buffet intensities of the two airplanes were of the same order. When compared on an angle-of-attack basis, it was found that the intensity-rise boundaries of the two airplanes were almost coincidental.

The maneuvering range of the Northrop X-4 was found to be limited by maximum attainable lift and control ineffectiveness and was not limited by the onset of high-intensity buffeting. The magnitude of the buffeting encountered was objectionable to the pilots only at normal-force coefficients close to maximum lift. No alleviating effect, insofar as buffeting is concerned, was produced by the absence of a horizontal tail.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 18, 1953.

REFERENCES

1. Sadoff, Melvin, Ankenbruck, Herman O., and O'Hare, William: Stability and Control Measurements Obtained During USAF-NACA Cooperative Flight-Test Program on the X-4 Airplane (USAF No. 46-677). NACA RM A51H09, 1951.

2. Sadoff, Melvin, and Sisk, Thomas R.: Summary Report of Results Obtained During Demonstration Tests of the Northrop X-4 Airplanes. NACA RM A50I01, 1950.

3. Sadoff, Melvin, and Sisk, Thomas R.: Stall Characteristics Obtained From Flight 10 of Northrop X-4 No. 2 Airplane (USAF No. 46-677). NACA RM A50A04, 1950.

4. Anon: Preliminary Report on High-Speed Wind Tunnel Tests of a 1/4th-Scale Reflection Plane Model of the Northrop XS-4 Airplane. CWT Rep. 69, Southern Calif. Cooperative Wind Tunnel, Oct. 28, 1948.

5. Vernier, B. R.: Ground Vibration Test for the Prediction of Flutter Safety. Rep. No. T-184, Northrop Aircraft, Inc., 1948.

TABLE I. - PHYSICAL CHARACTERISTICS OF NORTHROP X-4 AIRPLANE

Engines (two)	Westinghouse J-30-WE-7-9
Rating (each), static thrust at sea level, lb	1600
Airplane weight:	
Maximum (238 gal fuel), lb	7820
Minimum (10 gal trapped fuel), lb	6452
Wing loading:	
Maximum, lb/sq ft	39.1
Minimum, lb/sq ft	32.2
Center-of-gravity travel:	
Gear up, full load, percent M.A.C.	18.3
Gear up, post flight, percent M.A.C.	16.3
Gear down, full load, percent M.A.C.	18.6
Gear down, post flight, percent M.A.C.	16.7
Height, over-all, ft	14.83
Length, over-all, ft	23.25
Wing:	
Area, sq ft	200
Span, ft	26.83
Airfoil section	NACA 0010-64
Mean aerodynamic chord, ft	7.81
Aspect ratio	3.6
Root chord, ft	10.25
Tip chord, ft	4.67
Taper ratio	2.2:1
Sweepback (leading edge), deg	41.57
Dihedral (chord plane), deg	0
Wing boundary-layer fences:	
Length, percent local chord	30.0
Height, percent local chord	5.0
Location, percent semispan	90.0
Wing flaps (split):	
Area, sq ft	16.7
Span, ft	8.92
Chord, percent wing chord	25
Travel, deg	30
Dive-brake dimensions as flaps:	
Travel, deg	±60

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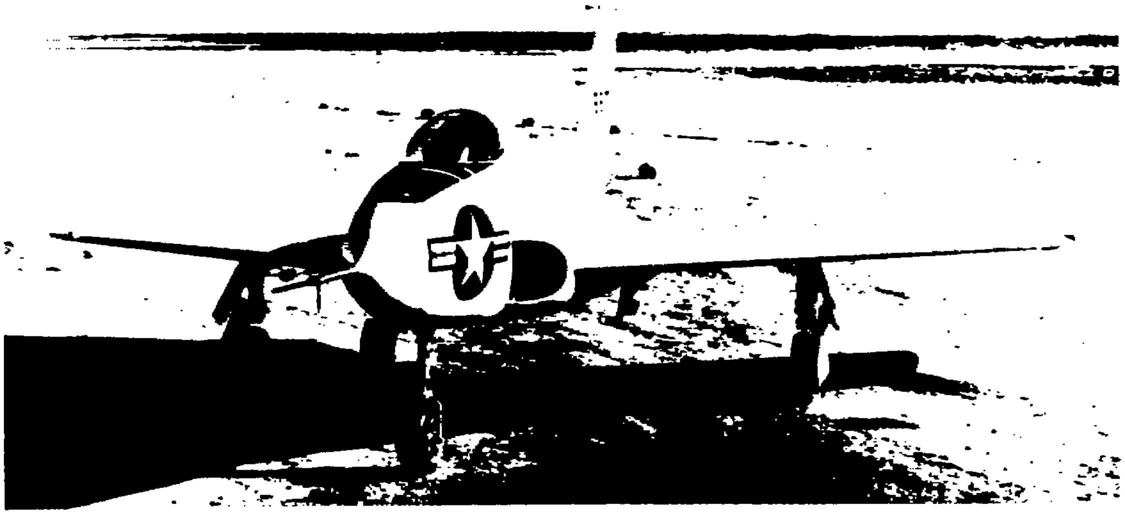
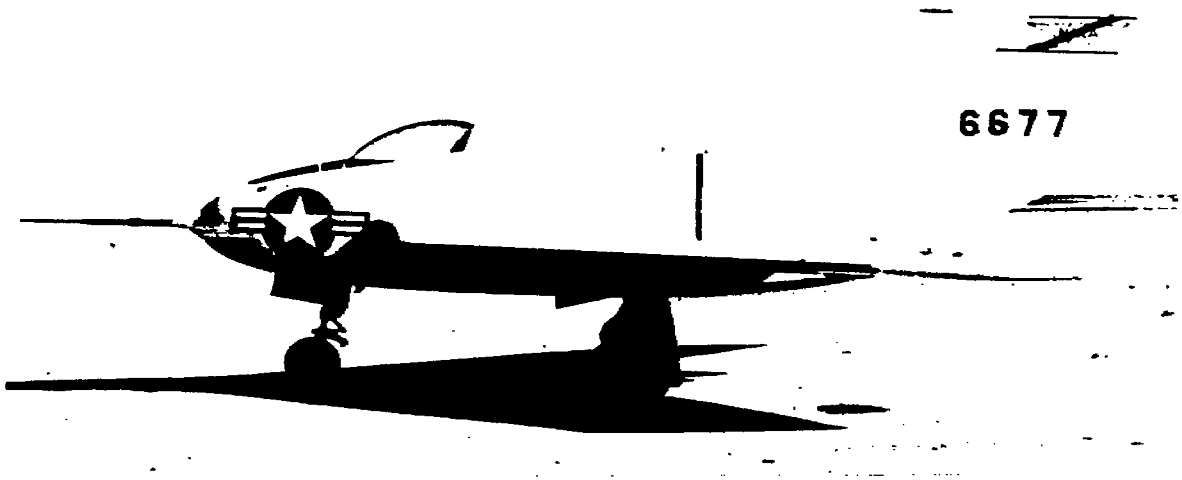
TABLE I. - PHYSICAL CHARACTERISTICS OF NORTHROP X-4 AIRPLANE - Concluded

Elevons:	
Area (total), sq ft	17.20
Span (two elevons), ft	15.45
Chord, percent wing chord	20
Movement:	
Up, deg	35
Down, deg	20
Operation	Hydraulic with electrical emergency
Vertical Tail:	
Area, sq ft	16
Height, ft	5.96
Rudder:	
Area, sq ft	4.1
Span, ft	4.3
Travel, deg	±30
Operation	Direct



(a) Three-quarter front view.



(b) Side view. L-71523

Figure 1.- Views of Northrop X-4 airplane.

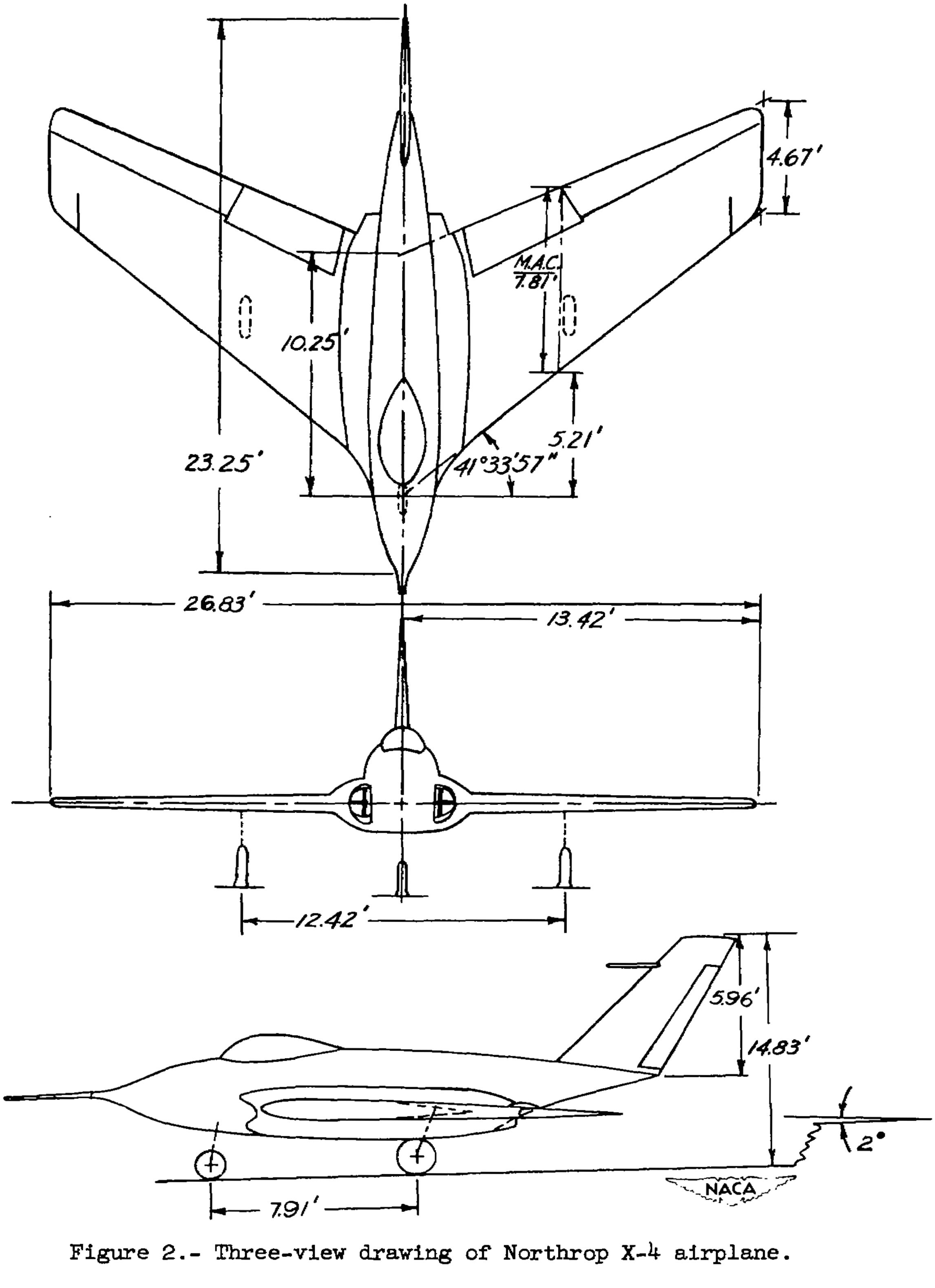
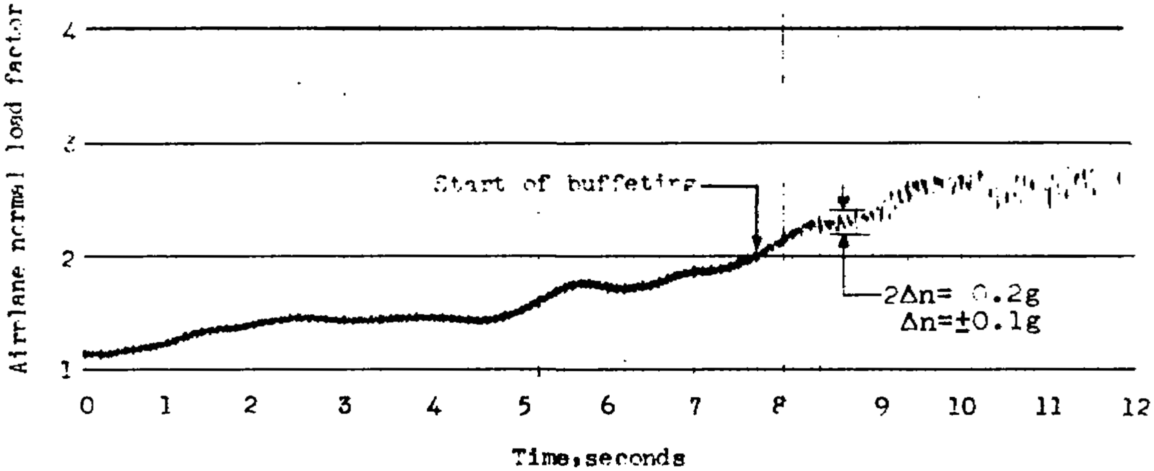
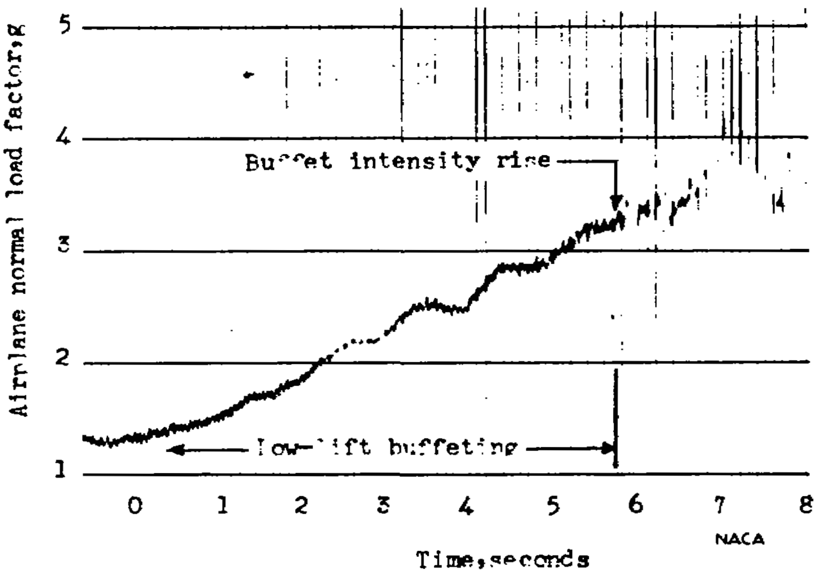


Figure 2.- Three-view drawing of Northrop X-4 airplane.



(a) $M \approx 0.61$.



(b) $M \approx 0.80$.

Figure 3.- Typical records of normal acceleration during buffeting. Northrop X-4 airplane; $h_p \approx 30{,}000$ feet.

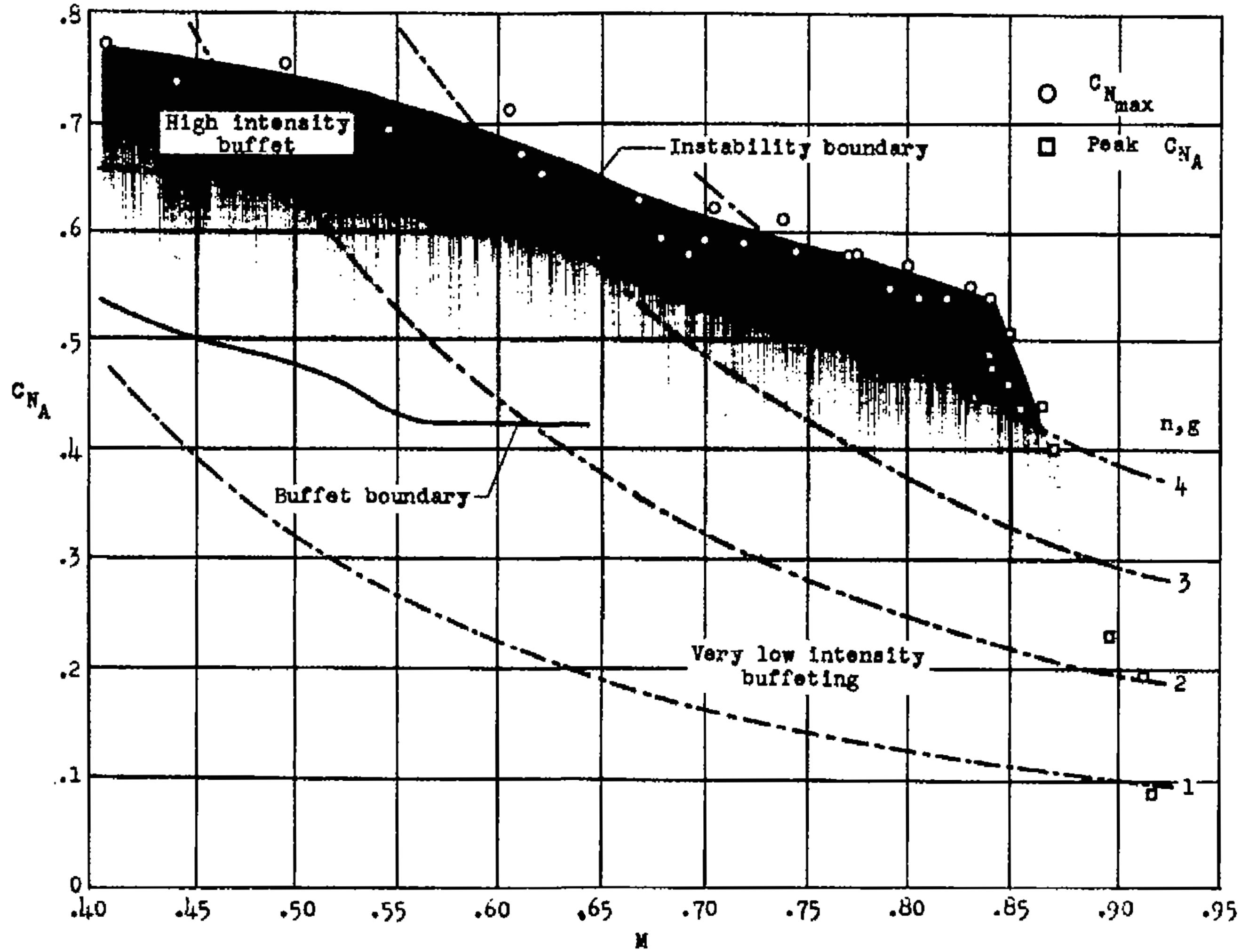


Figure 4.- Operational region of the Northrop X-4 airplane. $h_p \approx 30{,}000$ feet; $\frac{W}{S} = 35$.

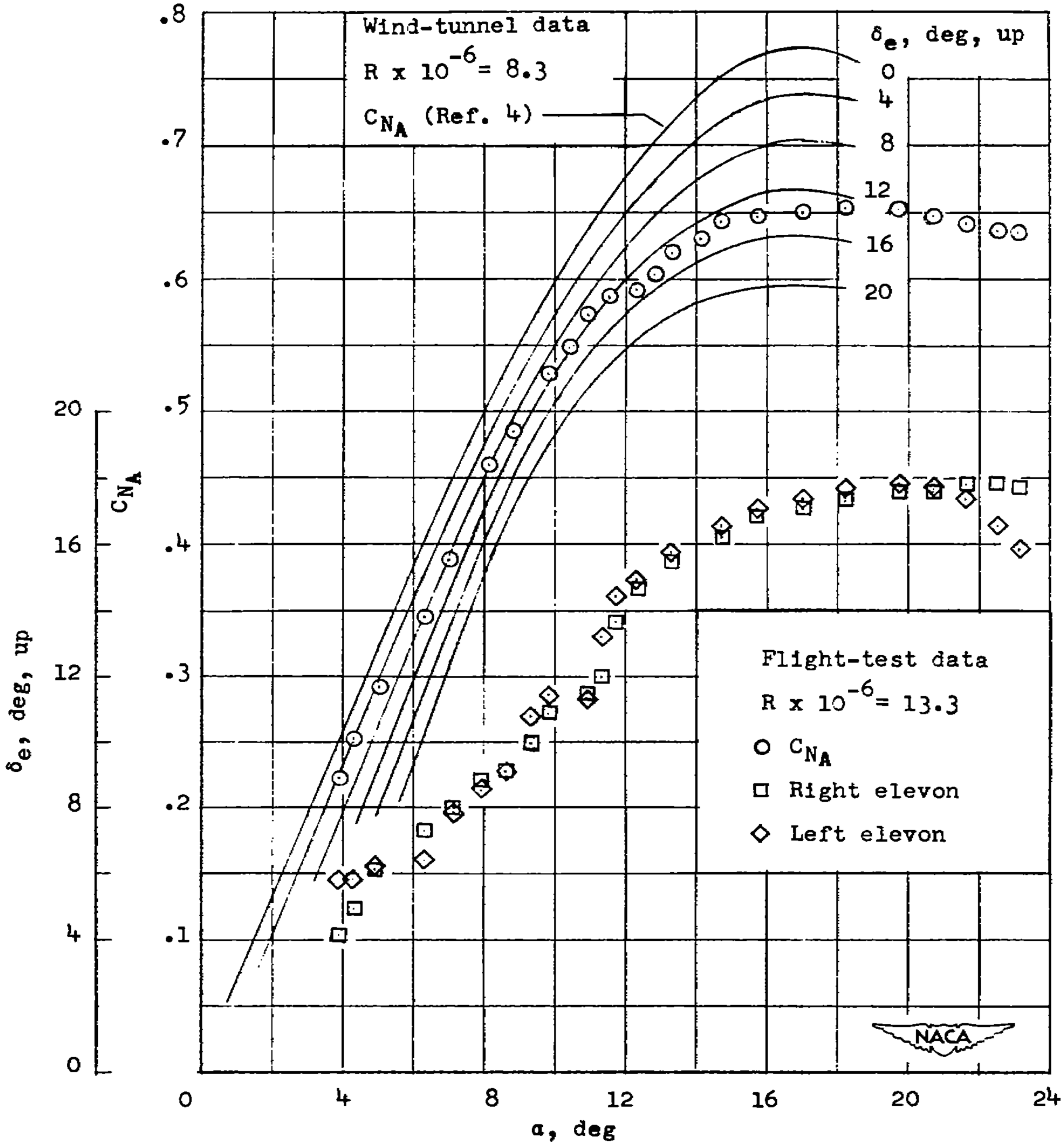
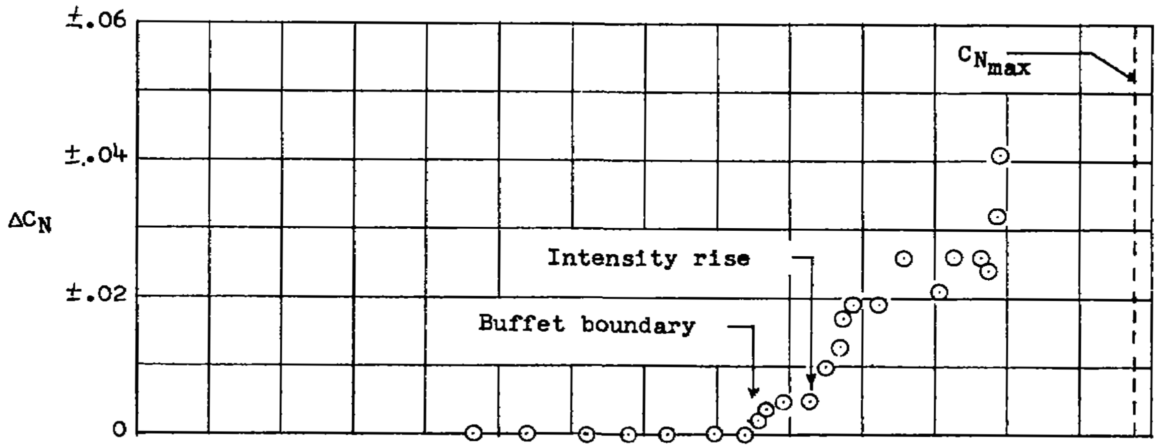
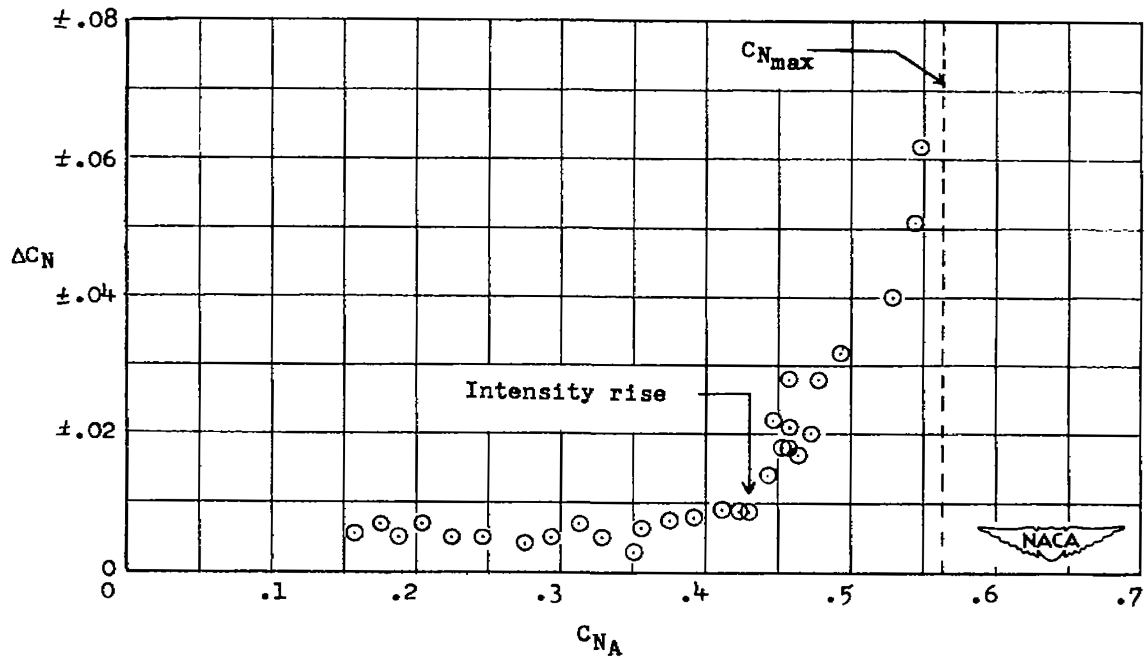


Figure 5.- Variation of flight-determined airplane normal-force coefficient and elevon positions with angle of attack and comparison with wind-tunnel normal-force coefficients at various elevon positions. $M \approx 0.6$.



(a) $M \approx 0.61$.



(b) $M \approx 0.80$.

Figure 6.- Typical variation of buffet intensity with airplane normal-force coefficient. $h_p \approx 30,000$ feet.

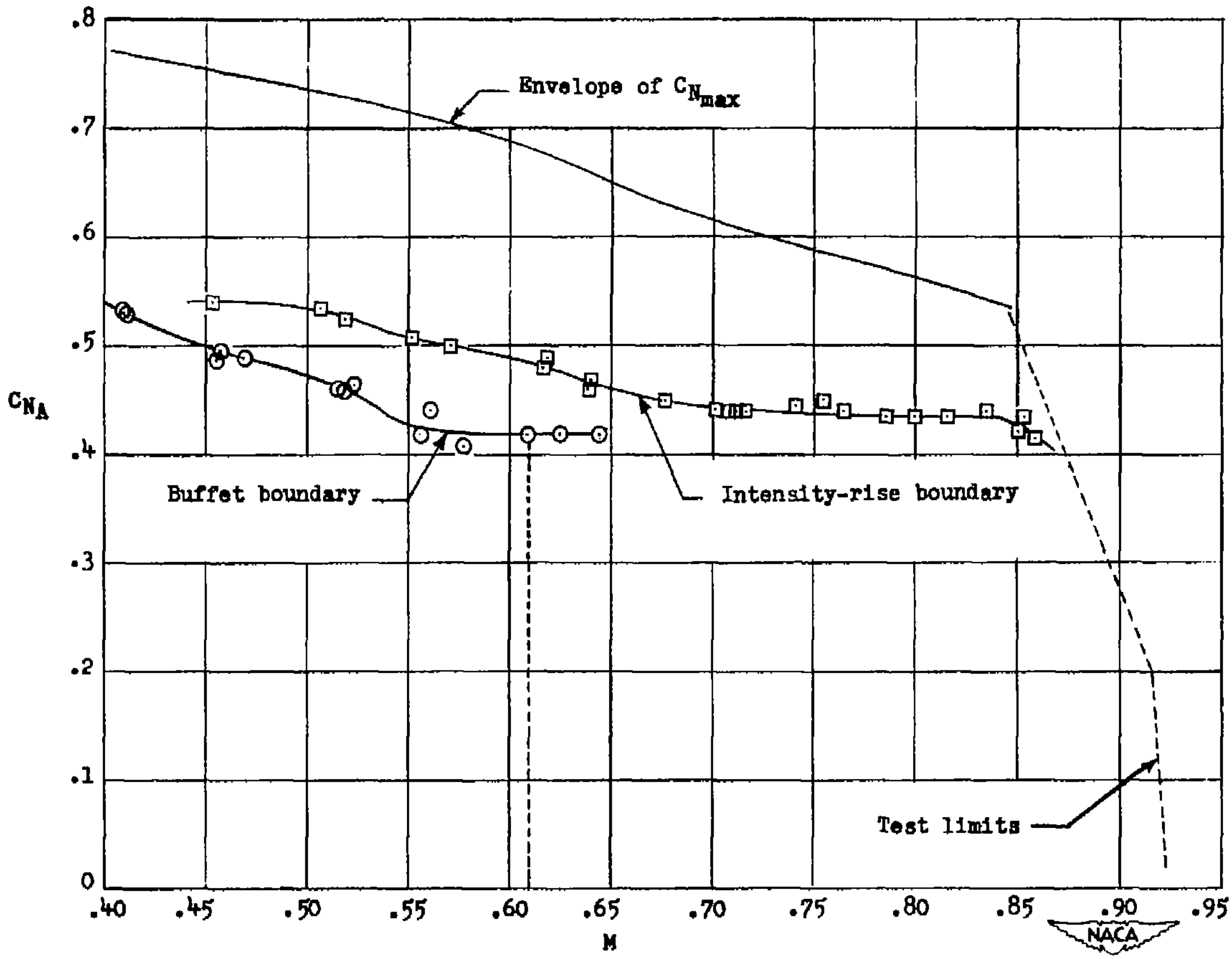


Figure 7.- The buffet boundary and buffet intensity-rise boundary for the Northrop X-4 airplane. $h_p \approx 30{,}000$ feet.

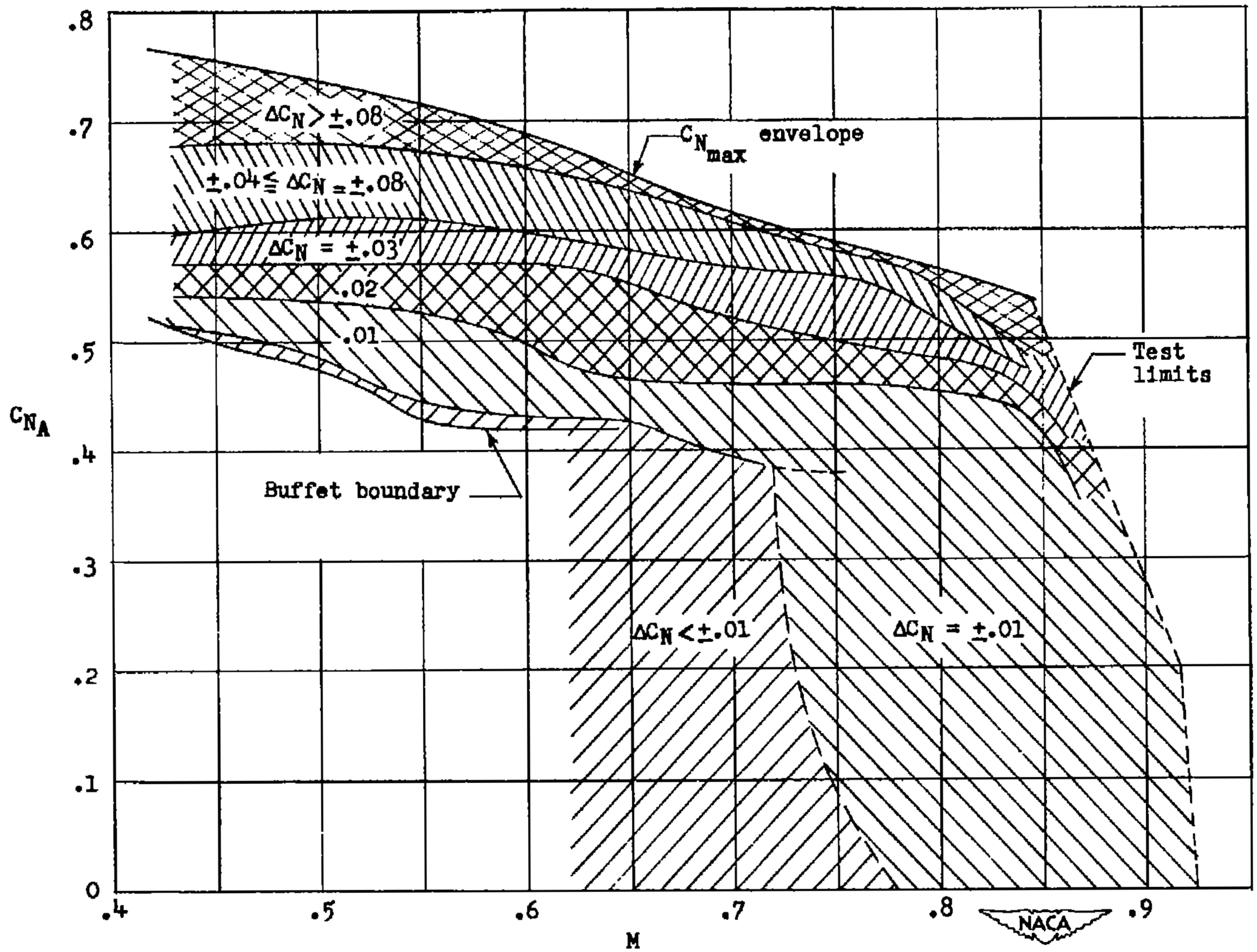


Figure 8.- The variation of buffet intensities with airplane normal-force coefficient and Mach number. Northrop X-4 airplane; $h_p \approx 30,000$ feet.

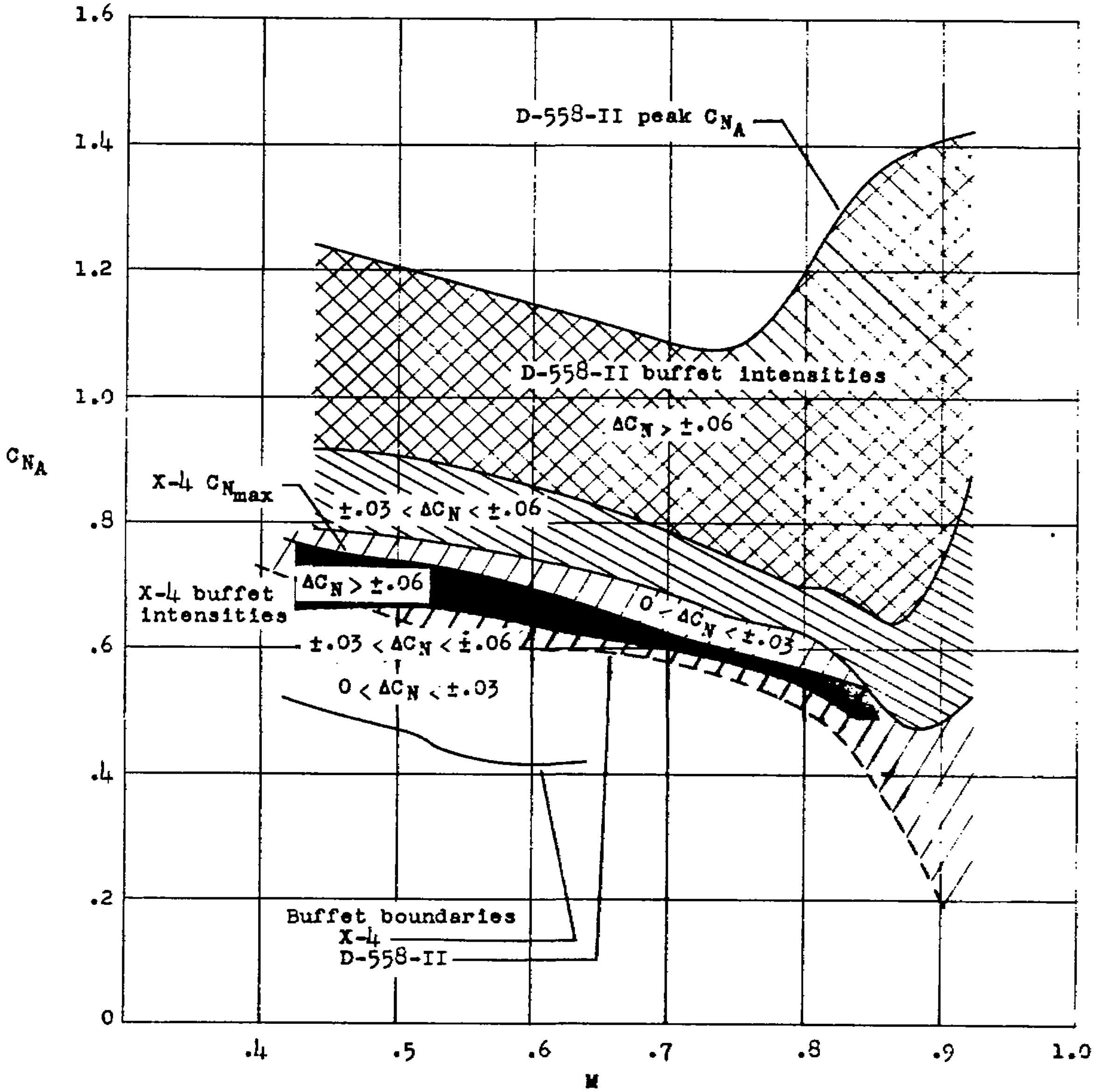


Figure 9.- Comparison of the buffet intensities experienced by the Northrop X-4 airplane with those encountered by the Douglas D-558-II airplane. $h_p \approx 30{,}000$ feet.

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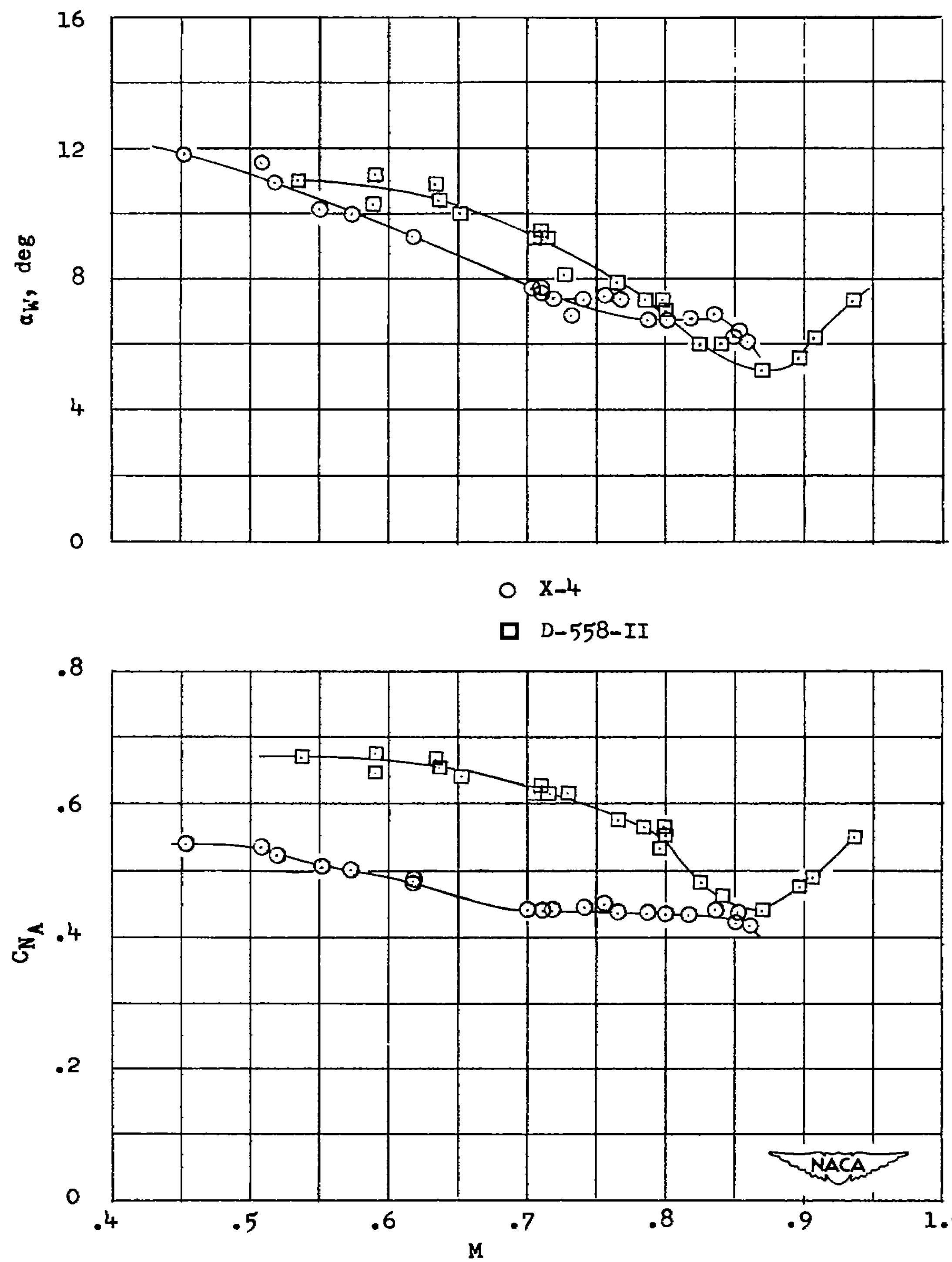

Figure 10.- Comparison of the buffet intensity-rise boundaries of the Northrop X-4 and Douglas D-558-II airplanes. $h_p \approx 30,000$ feet.

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